

COMPLEX TRANSVERSE AC MAGNETO-OPTIC SUSCEPTOMETER FOR
DETERMINATION OF VOLUME AND ANISOTROPY FIELD

DISTRIBUTION IN RECORDING MEDIA

CROSS-REFERENCE TO RELATED APPLICATION(S)

- 5 This application claims priority from Provisional Application No. 60/416,639, filed October 7, 2002 for "Highly sensitive complex transverse AC susceptometer using magneto-optical probe for accurate determination of volume and anisotropy field distribution in recording media" by G. Ju, R. Chantrell, H. Zhou, and D. Weller, which is incorporated by reference.

BACKGROUND OF THE INVENTION

The present invention relates generally to methods used to determine magnetic properties of materials. In particular, this invention relates to systems that determine the grain size distribution, σ_V , and anisotropy field distribution, σ_{HK} , in
5 thin film granular or nanoparticle material.

In order to achieve magnetic recording in advanced perpendicular media beyond 100 Gbits/in², it is necessary to have media with ultra-high anisotropy constant, K_U , and very narrow anisotropy field distribution, σ_{HK} . Increases in areal density of the recording media have relied on a reduction of the magnetic grain size,
10 V (where V is volume), and the grain size distribution, σ_V to keep media noise within acceptable levels while at the same time maintaining thermal stability. To achieve this goal, the media must be carefully designed and engineered to reduce both the grain size, V , and anisotropy field distribution, σ_{HK} .

In order to increase the areal density of a disc it is necessary to create
15 more bits on the surface area of the disc. Each bit consists of a plurality of grains, on the order of 10 to 100, that hold the magnetic state of each bit. Presently, grains are on the order of 10 to 20 nanometers in diameter, with advances demanding much smaller diameters. In order to increase areal density, it is necessary to either use fewer grains per bit or to decrease the size of the grains. It is undesirable to use fewer
20 grains per bit because this increases the error and noise associated with each bit as there are fewer grains left to hold the magnetic orientation of the bit. Thus, it is necessary to decrease the size of the grains in each bit to increase areal density.

Decreasing the grain size has limitations. The switching energy of a grain is the energy required to switch the magnetic orientation of the grain along
25 the easy axis.

$$E_B = K_U V (1 - H_{DC}/H_K)^2 \quad \text{Equation [1]}$$

The energy barrier, E_B , is a function of an anisotropy energy K_U (which is the energy difference between the easy axis and hard axis orientation of the grain), grain

volume V , the DC field strength H_{DC} , and anisotropy field strength H_K . Each grain also has an associated thermal energy, $k_B T$, that is the temperature dependent thermal energy of the grain, where k_B is Boltzmann's constant and T is the absolute temperature. It is desirable that this only happen during write operations by the writer. Since the energy barrier is a function of grain volume V , with small grains the thermal energy can be greater than the energy barrier. This can result in undesired switching of the grain. Thus, the grains of magnetic media should not be so small that the thermal energy of the grain is greater than the energy barrier. In other words, the anisotropy energy $K_U V$ of each grain must remain higher than the thermal energy $k_B T$.

The grains comprising the magnetic media are not uniform in size. They are distributed over a range of grain volumes (or grain diameters). Ideally, all grains would be of the same size in order to ensure each grain is at the optimal volume to overcome thermal switching and maximize areal density. This, however, is not possible. Thus, it is necessary to have as narrow a distribution of grain volume (or diameter) as possible near the optimal grain volume (or diameter) in order to eliminate small grains that can be switched by thermal energy. Similarly, it is necessary to have a narrow K_U distribution in order to insure that the grains are properly switching in a narrow range during the writing process by the writer, such that a narrow transition width will be achieved to support high recording density.

Media noise is dependent on grain size. Media noise is a result of "saw-toothed" transitions between bits on magnetic media. This means that one bit's region on the disc track is not clearly distinct from the next bit's region. These irregular boundaries result in noise as the reader transitions from one bit to the next. A low noise magnetic medium is accomplished by having small grain size. Smaller grain size helps average the arbitrary nature of the grains over more grains per bit, thus providing a smoother transition between bits. Decoupled grains also help to reduce media noise because the decoupled grains provide a more distinct transition

between bits as clear grain boundaries are present in the micro-structure between uncoupled grains.

Direct measurement of grain size distribution σ_V (or σ_D , where D is grain diameter) and anisotropy field distribution σ_{HK} is crucial, as it enables key experimental insights into the main factors controlling these distributions and allows development of experimental materials and processing strategies to reduce them. In particular, as advances in magnetic recording move toward the use of thin film granular material, σ_V and σ_{HK} become even more important. Accurate determination of σ_V and σ_{HK} , however, remains a challenge, especially in thin film decoupled granular material.

In thin film granular material, determination of grain size distribution and anisotropy field distribution is difficult. Magnetic measurements, such as susceptibility, are difficult in granular material since the magnetic signal generated by these grains is low. Also, thin films produce weaker signals because there is less material to produce a change in signal. Therefore, highly sensitive methods are needed.

Previously, both easy-axis and hard-axis hysteresis loops have been adopted to extract σ_{HK} . Papusoi et al., "Magnetic Anisotropy Field Dispersion Characterization of Advanced Perpendicular and Longitudinal Media," IEEE Transactions On Magnetics, Vol. 38, No. 4, July 2002, pp. 1687-1692. However, the extracted σ_{HK} is convoluted with the crystalline anisotropy angular dispersion and the grain size dispersion.

Other techniques have used the temperature dependence of the complex transverse AC susceptibility (T. Jonsson, et. Al. *J. Magn. Magn. Mater.*, **168**, 269 (1997)) or have used a Micro-SQUID noise technique (S.I Woods, et.al. *Phys. Rev. Lett.*, **87**, 137205 (2001)) to measure energy barrier distributions in superparamagnetic nanoparticles. However, since both of these methods rely on measurements in the superparamagnetic state, they are of limited value in assessing

dipsersions in thermally stable ferromagnetic media. This is because at temperatures near or above the Curie temperature needed to induce sufficient thermal fluctuations, the magnetic properties, spontaneous magnetization and anisotropy, and their dispersions are significantly different from respective values at the temperature of interest. Additionally, these methods do not allow for grain size distribution measurements.

In a recent paper in the theoretical field of susceptibility, which is herein incorporated by reference, Papusoi mathematically derive the relationship between the complex transverse AC Susceptibility with anisotropy field distribution, σ_{HK} , and grain size distribution, σ_V . Papusoi, "The Complex Transverse Susceptibility," Physics Letters A, Vol. 265, Issues 5-6, February 2000, pp. 391-402. Papusoi teaches that the measured complex transverse AC susceptibility contains information on both σ_V and σ_{HK} . However, the separation of σ_{HK} from σ_V in the complex transverse AC susceptibility was not shown. Papusoi's calculations depend on the thermal relaxation rate of individual grains, as relied on in the above mentioned methods. Papusoi teaches that the thermal relaxation can be controlled by applying a DC field. Thus, susceptibility calculations can be carried out at the temperature of interest without altering the magnetic properties of the materials, namely spontaneous magnetization and anisotropy.

Papusoi suggests a pick-up coil detection scheme for measuring complex transverse AC susceptibility in recording tape. This method, however, is not accurate enough for use on thin film decoupled magnetic material. Specifically, the pick-up coil method suggested by Papusoi creates too much noise in the system at low levels to detect the small changes created by the reorientation of the individual grains. The pick-up coil method requires applying an AC field with a coil and a DC field to the magnetic sample material. The AC coil is present within the DC field, which causes the AC coil to vibrate. Thus, the detecting pick-up coil also

vibrates when coupled with the AC coil. This causes noise greater than the susceptibility measurement in thin film granular material.

The pick-up coil method suggested by Papusoi also has another drawback when associated with measuring in magnetic recording media with a thin film top layer and a soft underlayer. The experiment Papusoi suggests uses a sample with a thickness of 200 nanometers. The area of interest in thin film magnetic recording media is the ultra-thin top and seed layers that have a thickness of ~20 nanometers. The pick-up coil method suggested by Papusoi will measure beyond the top and seed layers. The susceptibility measurement will then be an average of the whole sample, not just the top layers. Thus, the pick-up coil method is not able to obtain precise information from magnetic disc media with ultra-thin film top layers.

Thus, there is a need in the magnetic recording industry to accurately determine complex transverse susceptibility in ultra-thin film decoupled granular material so that σ_V and σ_{HK} can be accurately derived and de-convoluted.

BRIEF SUMMARY OF THE INVENTION

The present invention is a system and method for determining anisotropic field distribution and grain size distribution of ultra-thin film decoupled granular material. The invention utilizes a magneto-optical complex transverse AC
5 susceptometer to measure susceptibility of thin film decoupled media. The present invention is able to measure in thin film decoupled granular material because of its high sensitivity. This method is also capable of measuring susceptibility of ultra-thin film top layers of magnetic recording media.

Specifically, the invention indirectly determines σ_v and σ_{HK} by first
10 measuring transverse AC susceptibility as a function of an applied DC field, using the magneto-optical Kerr effect (MOKE). The complex components of the susceptibility are determined from the MOKE measurements. Values of σ_v and σ_{HK} are derived using curve fitting based on different sensitivities of imaginary susceptibility to σ_v and σ_{HK} at different DC field levels.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1A illustrates a schematic layout of one embodiment of the complex AC magneto-optic susceptometer of the present invention for use with magnetic samples having perpendicular anisotropy.

5 FIG 1B shows a plot of the energy barrier at various applied in-plane DC field strengths.

FIG. 2A shows a plot of the real and imaginary parts of the transverse susceptibility measured with the present invention.

10 FIG. 2B shows a plot of the fitting of the volume distribution and anisotropy distribution from the imaginary part of the complex transverse susceptibility.

FIG. 3A shows a plot of a comparison between the grain size distributions obtained by this invention and by transmission electron microscopy (TEM).

15 FIG. 3B is the TEM image used to obtain grain size distribution for comparison.

FIG. 4 shows a plot of the anisotropy distribution as obtained from the method of the present invention.

20 FIG. 5 shows a complex AC magneto-optic susceptometer of the present invention for use with magnetic samples having in-plane anisotropy.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

FIG. 1A illustrates a schematic layout of one embodiment of the complex AC susceptometer of the present invention which uses the magneto-optic Kerr effect (MOKE) to derive values of σ_v and σ_{HK} from magnetic sample 100. In this embodiment, magnetic sample 100 is a decoupled granular magnetic thin film having perpendicular anisotropy - - i.e. the easy axis of magnetization is perpendicular to the plane of magnetic sample 100. The MOKE complex AC susceptometer includes AC Helmholtz coil 102, function generator 104, electromagnet 106, laser 108 (which produces incident beam 110), mirror 112, polarizer 114, beam splitter 116, lens 118, reflected beam 120, Wollaston prism (or analyzer) 122, photodiodes 124A and 124B, differential amplifier 126, lock-in amplifier 128, and computer 130.

In FIG 1A, magnetic sample 100 is placed in an AC field, H_{AC} and a DC field, H_{DC} . The DC field, H_{DC} , is in the plane of sample 100, while the AC field, H_{AC} , is perpendicular to the plane of sample 100. H_{AC} is generated using AC Helmholtz coil 102 and function generator 104. H_{DC} is generated using an electromagnet 106.

He-Ne laser 108 is the light source for the magneto-optical Kerr effect probe. Incident beam 110 from laser 108 is reflected by mirror 112, and passes through polarizer 114, beam splitter 116 and lens 118. Incident beam 110 is reflected at the surface of sample 100 and undergoes a polarization alteration due to the magnetization of sample 100. Reflected beam 120 passes through lens 118 and is reflected by beam splitter 116 to a detection arm that includes Wollaston prism 122 and photodiodes 124A and 124B. Wollaston prism 122, or analyzer, is used to separate polarized beam components 120A and 120B of reflected beam 120. Photodiodes 124A and 124B provide positive and negative input signals to differential amplifier 126. The output of differential amplifier 126 is a signal

representing a difference in intensity of components 120A and 120B of reflected beam 120, which is proportional to the change of magnetization induced by the AC field. Lock-in amplifier 128, using as inputs a sync signal from function generator 104 and the output signal from differential amplifier 126, can determine the real and
5 imaginary components of the susceptibility. Finally, computer 122 acquires the data and derives separate values for σ_v and σ_{HK} from the complex transverse AC susceptibility. This derivation is possible because of the high sensitivity of the MOKE measurements and the use of a variable DC field. The differing sensitivity of the imaginary component of AC susceptibility to σ_v and σ_{HK} at high and low
10 DC fields allows computer 122 to derive separate values by curve fitting.

Papuso teaches that if the complex components of transverse AC susceptibility can be measured, convoluted information regarding the grain size, σ_v , and anisotropy field, σ_{HK} , distributions can be obtained, but does not disclose separating (deconvoluting) σ_v and σ_{HK} . Details are disclosed in the Papuso papers
15 disclosed above, which are incorporated by reference. The equations essential to understanding the advances of the present invention are explained briefly below in order to better disclose the operation of the present invention.

In thin film granular recording media, data is represented by the magnetic orientation of a bit. In each bit there are a plurality of grains. The grains
20 can be magnetically orientated in one of two ways along the easy axis of each grain. The magnetic orientation of the grains define the state of the bit. When data is written to a bit, the orientation of that bit is switched. In order to switch the bit, the energy barrier must be overcome. Normally, this is achieved by the writer of a disc drive system during write operations when the writer applies an external energy
25 source to the bit.

Figure 1B shows a plot of the energy barrier at various applied in-plane DC field strengths. The insert to Figure 1B shows a Stoner-Wohlfarth particle subject to two orthogonal fields: H_{DC} and H_{AC} .

For a Stoner-Wohlfarth single domain perpendicular grain, when a DC field is applied along the hard-axis direction in the film plane, the energy barrier between two symmetric energy minima is represented by the following equation

$$E_B = K_U V (1 - H_{DC}/H_K)^2 \quad \text{Equation [1]}$$

5 where K_U is the energy density, V is the grain volume, and $H_K = 2K_U/M_S$ is the anisotropy field (where M_S is the saturation magnetization). As can be seen from the equation, the energy barrier is a function of the grain volume, V , and the DC field, H_{DC} .

As stated earlier, thermal energy can also cause the grains to switch
10 orientation. The thermally activated switching rate, W , which represents the transition rate of the thermally activated reversal between two energy minima, is also a function of the DC field H_{DC} , the anisotropy H_K , the absolute temperature T , the Boltzman's constant k_B , the energy barrier E_B , the anisotropy energy K_U , and the thermal attempt frequency f_0 .

$$15 \quad W = f_0 \exp [-E_B/k_B T] \quad \text{Equation [2]}$$

$$W = f_0 \exp [-K_U V / k_B T (1 - H_{DC}/H_K)^2] \quad \text{Equation [3]}$$

Thus, the thermally activated switching rate, W , can be controlled by controlling the DC field applied to the sample material. As the DC field is increased, the lowered
20 energy barrier enhances thermal relaxation process, leading to both real and imaginary components of transverse AC susceptibility as disclosed by Papusoi.

The real component corresponds to the reversible switching between the two energy minima, while the imaginary part is caused by irreversible switching. By analogy, the DC field plays a similar role with respect to the complex AC
25 susceptibility measurements as the temperature. However, in conventional temperature dependent complex transverse AC-susceptibility, only the energy barrier distribution can be obtained.

In contrast, in the present invention, measurements are made over a range of DC field values. The field dependence of χ_T allows separation of σ_{HK} and σ_v . For the complex susceptibility χ_T , from the above energy barrier formula, the H_k amplitude and the dispersion (σ_{HK}) affect both the thermal stability factor $K_u V/k_B T$ and the field modulation factor $(1 - H_{DC}/H_k)^2$, while the grain size dispersion (σ_v) or only affects the stability factor $K_u V/k_B T$. When the DC field is large, the field modulation factor dominates, hence the χ_T is more sensitive to the H_k dispersion but less sensitive to the grain size dispersion. However, at small DC field, the contribution from the field modulation factor is small.

When an AC field is applied to the sample material along the easy axis direction, the energy barrier is modified to

$$E_B = K_U V [(1 - h_{DC})^2 + 2h_{AC} \cos\theta_0] \quad \text{Equation [4]}$$

where K_U is the energy density, V is the grain volume, h_{AC} is the DC field, h_{DC} is the AC field, and θ is the angular frequency. The occupation probability $n_1(t)$ at the initial energy minimum can be calculated from the Arrhenius-Neel law: $dn_1(t)/dt = -P [2n_1(t) - 1] = -f_0 \exp[-E_B/k_B T] [2n_1(t) - 1]$. Both real and imaginary parts of χ_T can be obtained accordingly. The real part is composed of thermal and non-thermal contributions. In addition, there is a singularity at $h_{DC}=1$. The imaginary part is only due to thermal relaxation processes:

$$\text{Im}(\chi_T) = \frac{M_s}{H_k} (-4W\omega\beta \frac{1 - h_{DC}^2}{4W^2 + \omega^2})$$

when $h_{DC} < 1$; and

$$\text{Im}(\chi_T) = 0$$

when $h_{DC} \geq 1$;

$$\text{Equation [5]}$$

where W is the thermally activated transition rate, $\beta = K_u V/k_B T$ and $\omega = 2\pi f_{AC}$. It is straightforward to show that $\text{Im}(\chi_T)$ peaks at $W = \omega/2$.

For thin film media with both grain size and anisotropy field distributions, the imaginary part is rewritten as

$$\text{Im}(\chi_T) = \frac{1}{V} \int_0^\infty \int_0^\infty 4W\omega\beta \frac{1 - \left(\frac{h_{DC0}}{h_K}\right)^2}{4W^2 + \omega^2} VF(V)dV \left] \frac{G(h_K)}{h_K} dh_K$$

Equation [6]

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where V is the grain volume, W is the thermally activated switching rate, ω is the AC frequency, $\beta = K_U V / k_B T$, $G(h_K)$ is an assumed lognormal function of the anisotropy field distribution, $F(V)$ is an assumed lognormal function of the grain size distribution, and h_{DC0} is the DC field strength. Thus, we have an equation having as parameters the imaginary component of susceptibility, volume, anisotropy, the DC field, and the AC field. The imaginary component of the susceptibility can be measured and the values of the applied DC and AC fields are known. That leaves the two unknown parameters that are of interest, V and H_K , for which σ_V and σ_{HK} can be solved for with a fitting technique.

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Returning to FIG. 1A, the invention can be more accurately described in light of the required measurements and calculations. Magnetic 100 is placed in a DC field, H_{DC} , such that H_{DC} is in the plane of sample 100, and perpendicular to the easy axis of magnetization. Sample 100 is also positioned such that an AC field is applied perpendicular to the plane of sample 100 (and parallel to the easy axis). A 5 to 80 Oe AC field, H_{AC} , is generated using Helmholtz coil 102. The AC field, H_{AC} , is swept over a frequency range of 5 to 2500 Hz using a function generator 104. The DC field is swept over a +/- 20 kOe range using electromagnet 106.

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The DC field is applied to tune the relaxation rate such that the grains are switching on the same time scale of the applied AC field, which gives rise to large contribution to $\text{Im}(\chi_T)$. As the DC field is swept through a range of values, the energy barrier of certain grains will change according to Equation [4], and the

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portion of the grains contributing to $\text{Im}(\chi_T)$ depends strongly on the volume and anisotropy energy of each grain. This can be seen in Equation [5].

The transverse AC susceptibility of the sample material is measured using the magneto-optic Kerr effect. A small change of the perpendicular magnetization induced by the AC field is measured by the polar magneto-optical Kerr effect using the differential detector scheme shown in FIG. 1A. The transverse AC-susceptibility is defined as the ratio of the AC field induced perpendicular magnetization and the AC field strength. Susceptibility is defined as the ratio of the AC field induced perpendicular magnetization and the AC field strength. The MOKE probe of this invention is able to determine the complex parameters of AC susceptibility as a function of an applied DC field in thin film granular material.

The calibration of the measured Kerr angle against the magnetization was performed by static measurement of the Kerr angle as a function of the in-plane field after initially saturating the sample out of plane. This technique is further described in Ju et al., J. App. Phys., Vol. 93, No. 10, May 2003, pp. 7846-7848, herein incorporated by reference.

Incident beam 110 is reflected at the surface of sample 100. This is an important feature for determining susceptibility in thin film magnetic media. When determining the susceptibility of thin films, it is important to only measure the top layer and not have any influence of any underlying layers. The finite penetration depth and the high sensitivity of the magneto-optical Kerr effect are ideal to measure the transverse AC susceptibility of thin film magnetic media, even in the presence of a magnetic soft underlayer. The invention also achieves high sensitivity by eliminating excess noise from the measuring system. Laser 108 (the source of incident beam 110) is mechanically isolated from the applied DC and AC fields. This eliminates vibration from the system, which eliminates noise.

Both the real and imaginary parts of the transverse AC susceptibility are measured by lock-in amplifier 128, which uses phase sensitive lock-in detection

to tune to the in- and out-of-phase components with the AC field. The susceptibility of sample 100 is recorded using computer 130 for a whole cycle of the applied AC field at each step in the DC field sweep. This gives rise to the three of the five variables in equation [5] at every DC field strength and AC frequency of interest.

5 The remaining two variables, σ_V and σ_{HK} , can be determined using a fitting technique, also done by the computer 130.

FIG. 2A and FIG. 2B show plots of the experimental measurements of the complex transverse susceptibility as measured by the magneto-optical Kerr effect. FIG. 2A shows the real and imaginary parts of the transverse susceptibility

10 $\text{Re}(\chi_T)$ and $\text{Im}(\chi_T)$, at an AC field frequency of 500 Hz measured on a CoCrPt perpendicular alloy medium. FIG. 2B shows the fitting of the volume distribution and anisotropy distribution from the imaginary part of the complex transverse susceptibility. As shown in Fig. 2B, the $\text{Im} \chi_T$ data at fields smaller than about $H_{DC}=7.5\text{kOe}$ (the negative peak of $\text{Im} \chi_T$) are more sensitive to the grain size

15 dispersion. The data at DC fields higher than 7.5kOe are more sensitive to the H_K dispersion. Hence, both grain size and H_K dispersions can be extracted by fitting the (χ_T) data, which yields a best fit with a $\sigma_D / \langle D \rangle$ of 0.27 and $\sigma_{HK} / \langle H_K \rangle$ of 0.09. The fitting is performed by first deriving a value of σ_{HK} that best fits the higher DC field data. That value of σ_{HK} is then used in deriving the value of σ_V (or σ_D) that

20 best fits the data at the lower DC field levels.

FIG. 3A shows a comparison between the grain size distribution measurements obtained by this invention and by TEM. Assuming a lognormal function for both distributions, a grain size dispersion of $\sigma_D / \langle D \rangle = 0.27$ with the mean size $\langle D \rangle = 11.5 \text{ nm}$ was found for the present alloy medium. The result agrees

25 well with the grain size distribution, $\sigma_D / \langle D \rangle = 0.26$, obtained from plane-view TEM grain size analysis. FIG. 3B is the TEM image used to obtain grain size distribution for comparison to the results of the present invention.

FIG. 4 shows a plot of the anisotropy distribution as obtained from the method of the present invention. A mean anisotropy $\langle H_K \rangle = 13.2 \text{ kOe}$ with a dispersion $\sigma_{HK} / \langle H_K \rangle$ was extracted.

Micromagnetic simulations indicate that the imaginary part of the transverse AC susceptibility is not very sensitive to angular dispersions and intergranular interactions, while the real part is much more sensitive to such effects. This is the primary reason that we use the imaginary susceptibility data to extract the distribution values in this invention. The method disclosed is valid for granular media with easy-axis distributions and intergranular interactions.

With the present invention, accurate measurements can be made to determine grain size distribution σ_v and anisotropy field distribution σ_{HK} in magnetic thin film granular material. This provides an important analytical tool needed in the continuing efforts to develop magnetic media capable of ever-increasing areal density.

Even though the invention has been described in use on media with perpendicular anisotropy, the measurement technique can also be applied for media with in-plane anisotropy. It can also be applied to sample formed by magnetic nanoparticles.

FIG. 5 shows an embodiment of the system of the present invention used to determine anisotropy field distribution and volume distribution in magnetic sample 200, which has in-plane anisotropy (i.e. an easy axis in the plane of the sample). The system of FIG. 5 is generally similar to the system of FIG. 1A, and similar components have the same reference numeral. In FIG. 5, magnetic sample 200 is placed in an AC field, H_{AC} parallel to the easy axis and a DC field, H_{DC} perpendicular to the easy axis. H_{AC} is generated using AC Helmholtz coil 102 and function generator 104. H_{DC} is generated using an electromagnet 106, and is varied so that susceptibility measurements are made over a range of the H_{DC} values.

Incident beam 110 from laser 108 passes through polarizer 114 and lens 118A and strikes the surface of sample 200. Incident beam 110 is reflected at the surface of sample 200 and undergoes a polarization alteration due to the magnetization of sample 200. Reflected beam 120 passes through lens 118B to a
5 detection arm that includes Wollaston prism 122 and photodiodes 124A and 124B. Wollaston prism 122 separates polarized beam components 120A and 120B, which are detected by photodiodes 124A and 124B. The output of differential amplifier 126 is a signal representing the detected difference in intensity of components 120A and 120B, which is proportional to the change of magnetization induced by the AC
10 field. Lock-in amplifier 128, using as inputs a sync signal from function generator 104 and the output signal from differential amplifier 126, determines the real and imaginary components of the susceptibility. Finally, a computer 122 acquires the data and derives separate values for σ_v and σ_{HK} from the complex transverse AC susceptibility as described above.

15 Although the present invention has been described with reference to preferred embodiments, workers skilled in the art will recognize that changes may be made in form and detail without departing from the spirit and scope of the invention.